GEOMETRIC MODELING OF FLASHOVER CONFIGURATIONS IN METALLIZED POLYPROPYLENE FILM

E. M. Halstead, A. D. Caulcrick, J. L. Zirnheld
Energy Systems Institute, University at Buffalo
312 Bonner Hall, Buffalo, NY 14260
H. Singh
RDECOM-ARDEC, Advanced Energy Armament Systems Center
Bldg. 65N, Picatinny Arsenal, NJ 07806

Abstract

The phenomenon of surface flashover on Metallized Polypropylene Films (MPF) is a highly complex process of which very little is known. In order to begin to better understand this phenomenon, a computer model was developed to simulate current waveforms obtained in experiments. Expressing the entire system in terms of the parasitic elements of the film to form an RLC circuit, a mathematical model was used to describe the time dependent behavior of the current waveform through the film. A C++ program utilizing the Runge-Kutta method of solving differential equations was used to solve the computer model. These results led to a series of proposed experiments to determine the validity of the model and to better understand the physical mechanisms behind this class of surface flashover. When completed, these investigations will answer several questions regarding flashover and will lead to practical applications and further research.

I. INTRODUCTION

Surface flashover is a phenomenon in which electrical arcing occurs on the surface of a material. In this research, many experiments have been performed to better understand this class of flashover. The purpose of this work is to build upon previous studies in order to gain more insight into the physical processes involved.

A. Background Information

Many surface flashover experiments were performed using metallized polypropylene film (MPF). To do this, an electrically switched pulsed power source was connected to a ¾" x 12" MPF plain sample via stainless steel electrodes. The pulser was charged to 2.5 kV, and then discharged across the film.

Experimental results obtained from oscilloscope readings after flashing several samples of MPF was similar to that given in Figure 1 as shown below. There was a sharp rise time in the current waveform peaking off at approximately 17 amps and the time duration of the event was approximately 192µs.

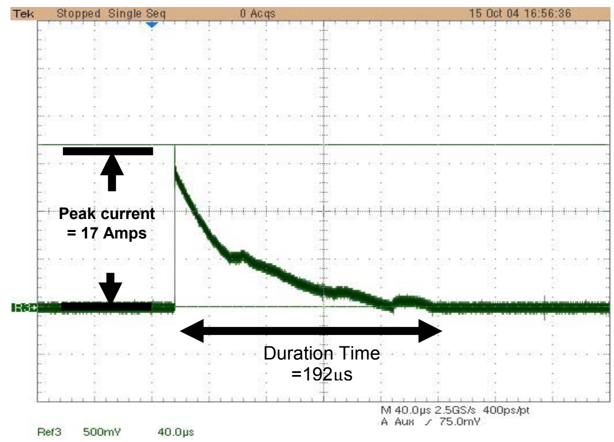

Figure 1. Experimental results of a test done on a plain MPF sample

B. Objectives

- Develop a computer model to simulate surface flashover of metallized polypropylene film

- Design a series of experiments to test the hypotheses regarding the physical mechanisms of flashover

II. DESIGN PROCEDURE

A. Model

To start the process of modeling of surface flashover, a basic schematic diagram incorporating the pulser source and the parasitic elements of the film was created. This is shown in Figure 2. Since the capacitance of the pulser is much larger than the parasitic capacitance of the film, the circuit could be made even simpler by removing Cp. A mathematical model can now be easily fit to this RLC circuit. The differential equation describing the behavior of this system is given by Eq. 1.

$$L\left(\frac{\partial^2}{\partial t^2}\mathrm{q}(t)\right)+R\left(\frac{\partial}{\partial t}\mathrm{q}(t)\right)+\frac{\mathrm{q}(t)}{C}=V\mathrm{e}^{\left(-\frac{t}{RC}\right)} \tag{1}$$

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
JUN 2005	**N/A**	-

4. TITLE AND SUBTITLE
Geometric Modeling Of Flashover Configurations In Metallized Polypropylene Film

5a. CONTRACT NUMBER
5b. GRANT NUMBER
5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER
5e. TASK NUMBER
5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Energy Systems Institute, University at Buffalo, 312 Bonner Hall Buffalo, New York, 14260

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002371. 2013 IEEE Pulsed Power Conference, Digest of Technical Papers 1976-2013, and Abstracts of the 2013 IEEE International Conference on Plasma Science. IEEE International Pulsed Power Conference (19th). Held in San Francisco, CA on 16-21 June 2013., The original document contains color images.

14. ABSTRACT
The phenomenon of surface flashover on Metallized Polypropylene Films (MPF) is a highly complex process of which very little is known. In order to begin to better understand this phenomenon, a computer model was developed to simulate current waveforms obtained in experiments. Expressing the entire system in terms of the parasitic elements of the film to form an RLC circuit, a mathematical model was used to describe the time dependent behavior of the current waveform through the film. A C++ program utilizing the Runge-Kutta method of solving differential equations was used to solve the computer model. These results led to a series of proposed experiments to determine the validity of the model and to better understand the physical mechanisms behind this class of surface flashover. When completed, these investigations will answer several questions regarding flashover and will lead to practical applications and further research.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**SAR**	**4**	

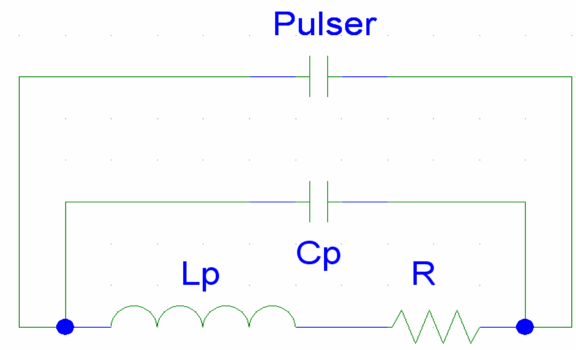

Figure 2. Flashover circuit model for the mathematical circuit analysis.

The variables L, q, R, C, V, and t represent inductance, charge, resistance, capacitance, voltage, and time, respectively. A C++ program was developed with the help of Dr. Gonsalves of the Physics Department at the University at Buffalo to numerically solve the differential equation using the Runge-Kutta method. The advantage of this program over a normal circuit simulation program was that the values of the circuit elements could be entered as functions of time. This is clearly important because the film is being damaged over the course of each capacitor discharge, and this damage will change the properties of the film. The program also outputs the results into a data file which could be plotted. In order to properly solve the differential equation, values for all of the variables and the initial conditions needed to be specified.

The given resistivity of the metallized polypropylene film was 7 Ω/square. Since the sample was ¾" x 12", it could be treated as sixteen ¾" x ¾" squares in series. This yielded a total equivalent resistance of 112 Ω for the entire sample.

B. *RLC Calculations*

The lumped element equivalent resistance, inductance, and capacitance of the film were also obtained experimentally at small signal levels. A function generator was connected across the film and the frequency ω_0 was adjusted until resonance was achieved. Then the frequency was varied to obtain the bandwidth B. Using these two data values along with Eqs. 1 and 2, the capacitance and inductance could then be calculated.

$$\omega_0 = \frac{1}{\sqrt{LC}} \tag{2}$$

$$B = \frac{R}{L} \tag{3}$$

The resonance frequency obtained was 12.378 Mrad/s and the bandwidth was 3.204 Mrad/s. This means that the parasitic inductance of the film was approximately 6.242 μH and the parasitic capacitance is 1.046 nF. Dividing the function generator voltage by the current through the film yielded an equivalent resistance of 20 Ω. The only other numbers that were needed in order to run the program were the initial conditions. The initial current was zero, and the initial charge was given by the product of the capacitance and the voltage. The capacitance of the capacitor in the pulser was 2.6 μF and the voltage across the capacitor was 2.5 kV. This means that the initial charge was $6.5\text{x}10^{-3}$C.

When these numbers were entered into the program, the current waveform in Figure 3 was obtained.

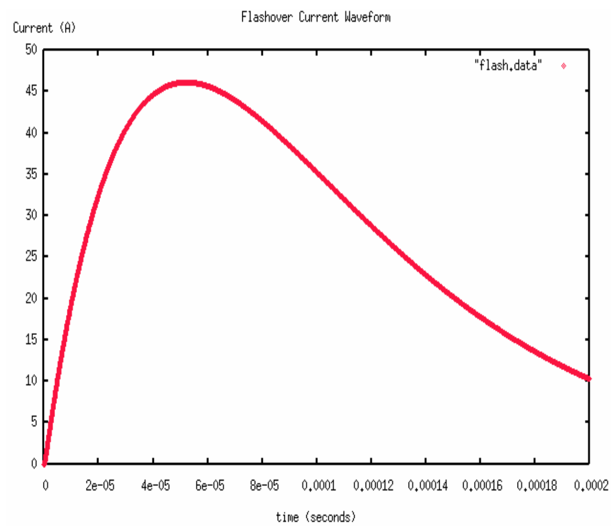

Figure 3. Flashover current waveform with the model developed in this study.

This was close to the current waveform obtained in the experiments (Figure 1) except that the current increase was too slow. However, if the capacitance is changed slightly to about 1 μF, a much different waveform results. This is shown in Figure 4.

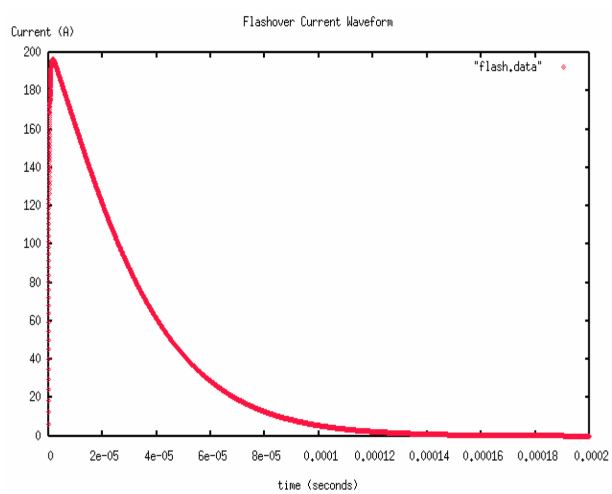

Figure 4. Flashover current waveform with 1 μF capacitance.

This produced a much sharper rise time and gave virtually the same time scale as the experiments yielded.

Unfortunately, it also results in a much higher peak current. Nevertheless, this model shows that the current waveform exhibits a very sensitive dependence on capacitance. This leads to the first proposed further experiment.

C. Configuration/Design Analysis

Since the pulsed power source had a capacitor already built into it, the best way to test the current waveform's dependence on capacitance would have been to place a capacitor in parallel with the capacitor in the pulser. Ideally, it should be the same type of capacitor. After trying a few different capacitances, the results were compared with those of the computer model.

It was also determined from the computer model that the current waveform was affected very little for small changes in inductance. For example, changing the inductance to 1 μH created no noticeable change from the waveform in Figure 4. This result is shown in Figure 5.

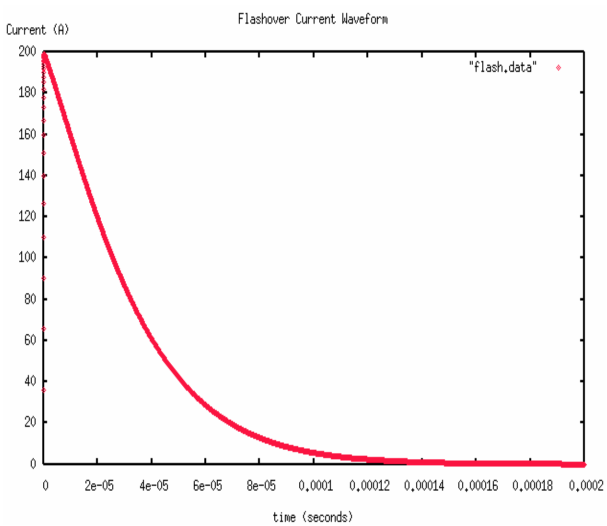

Figure 5. Current waveform after small change in circuit inductance.

This result leads to the second proposed further experiment. If the film sample were to be wound around a cylindrical core in a spiral fashion, there should be an increase in its inductance. The exact increase in inductance would depend on how tightly the film was wound. The material in the cylinder could be made out of anything that is not ferromagnetic. If the material in the cylinder were ferromagnetic, the inductance may be large enough to affect the current waveform. Experimental results could once again be compared with those of the computer model.

The third and fourth proposed experiments will test the hypotheses that are not based on the computer model. The first hypothesis is that the vaporization of the metallization occurs over areas where there are defects or impurities in the polypropylene film and/or variations in the metallization structure. It is reasonable to assume that the current moves across the film as a sheet current. If this is the case, why then would only strands of metallization be vaporized? Since polypropylene has a higher thermal conductivity (0.2 W/m-K) [3] than air (0.025 W/m-K) [4], the resistive heat generated by the current will try to conduct out through the film. However, if there is a defect or impurity in the film, the heat may not conduct as well. The metallization over these areas could vaporize first.

To test this hypothesis, one would need to either damage or remove the polypropylene under the metallization. One easy way to attempt to damage the polypropylene was to crease the film. If vaporization of the metallization occurred along the crease, then one of two things must be true. Either the polypropylene was damaged enough to affect its thermal conductivity, or more current was drawn to the crease because of the change in geometry. Another way to test the hypothesis would be to melt the polypropylene with a heat gun. This would likely create non-homogeneity in the structure of the film that would affect its ability to thermally conduct uniformly. If the metallization over this targeted area vaporized, then the hypothesis is most likely correct.

The final proposed experiment involves the process by which arcing occurs. It is believed that the arcing may be the result of liberation of ions that occurs during the vaporization of the metallization. While this may be the case, it is also known that the voltages that are used are high enough to create electric fields that can breakdown air, which would then lead to arcing. To test this, a setup must be created in which arcing occurs over an area where the metallization has already been removed. An eraser could be used to remove the metallization across the width of the film. Since the dielectric breakdown of air occurs when the electric field is $3x10^6$ V/m, [5] arcing should occur if the band of removed metallization has a width of 5/6 mm. However, the voltage drop across the rest of the film must be taken into account. This means that the film should be made wider to reduce the voltage drop and that the band of removed metallization should have a width of no more than half of a millimeter. This should create an electric field strong enough to cause the dielectric breakdown of air, which would in turn lead to arcing. In a normal experiment, this very same situation is likely to occur if a thin band of metallization across the film is vaporized. This would show that while the presence of liberated ions may make electrical arcing more probable, it is not necessary for the arcing to occur. If this experiment is performed on a ¾" x 12"sample and arcing fails to occur, then the liberation of ions is most likely responsible for the arcs.

III. CONCLUSIONS

Future research aims will include accurately determining the resistance, inductance, and capacitance of the film not only in the planar geometry, but in a cylindrical and spiral geometry as well. If these

measurements are repeated after the sample is used in a flashover experiment, it will be possible to create a more accurate model of how the resistance, inductance, and capacitance change as a function of time.

A second goal will be to incorporate the surface arcing into the computer model. This is important to incorporate because the arcing is a voltage and time dependent process, and each arc will only extinguish after the voltage has dropped below a certain critical value. In order to do this, it will be necessary to determine the threshold current at which the process of vaporization starts to occur. Therefore, a current dependent process will trigger the voltage dependent surface arcing.

The most important goal, however, will be to carry out the proposed further experiments set forth in this preliminary study. The results from those experiments will not only increase the knowledge of the flashover process, but will hopefully engender more ideas for additional experiments to perform.

IV. ACKNOWLEDGEMENTS

Effort sponsored by the U.S. Army's Advanced Energy Armament Systems Center at RDECOM-ARDEC, under grant number DAAE30-03-1-0200. The U.S. Government is authorized to reproduce and distribute reprints for Governmental purposes notwithstanding any copyright notation thereon. The views and conclusions contained herein are those of the authors and should not be interpreted as necessarily representing the official policies or endorsements, either expressed or implied, of the Department of Defense or the U.S. Government. Distribution statement A. Approved for public release.

V. REFERENCES

[1] J. D. Buneo, J. L. Zirnheld, K. M. Burke, J. B. Kirkland, E. M. Halstead, A. J. Halstead and W. J. Sarjeant, "Losses in pulsed dc fusing systems," in Proc. of the 14th IEEE International. Pulsed Power Conf., Dallas, TX, Jun. 15-18, 2003, pp. 1382-1384.

[2] J. D. Buneo, J. L. Zirnheld, K. M. Burke and W. J. Sarjeant, "Thin film geometry influence on fusing wave shape," in Proc. 2004 IEEE Power Modulator Conf., San Francisco, CA, May 23-26, 2004. 4 pages.

[3] Xiaoguang Qi, Zhong Zheng, and Steven Boggs, "Computation of electro-thermal breakdown of polymer films," Electrical Insulation Research Center, University of Connecticut. p. 2.

[4] Thermal conductivity for some common material. Available Online: http://www.engineeringtoolbox.com/24_429.html [December 19, 2004]

[5] Alice Hong. Electric Field to Produce Spark in Air (Dielectric Breakdown). (2000). Available Online: http://hypertextbook.com/facts/2000/AliceHong.shtml [December 19, 2004]

[6] W. G. Chace, H. K. Moore, *Exploding Wires*. Vol. I. Plenum Press, New York, 1959.